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Toward 21% efficiency nPERT solar cells with selective back surface field technique

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Abstract

We have demonstrated 20.83% large-area conversion efficiency with selective Back Surface Field(s-BSF) on the n-type Passivated Emitter, Rear Totally (nPERT) cell structure. Industrial 156mm (6" inch) n-type Czochralski mono-crystalline silicon wafers were used as substrates. In this kind of cell, we employed a single-side texture on the boron emitter side. We use AlO_X and SiN_X dielectric stack as ARC and passivation. The unique point is on the cell's rear side, we use the phosphorous ion implantation to form the Back Surface Field (BSF). Due to the flexible on the implant process, we can choose different implant mask pattern to form the heavy doping region to achieve the selective Back Surface Field(s-BSF) structure. Finally we use the industrial screen printing technique to form the metal contact. The front (boron) side is printed with Ag/Al paste and the rear (phosphorous) side is with two printing steps; at the first step, we use high solid content and firing-through silver paste to form the contact on the heavy doping region, and second, we use the low solid content and non-firing through silver paste to connect all the metal contact formed on the first step. Finally, we use the fast firing furnace to co-fire the sample. The champion batch shows average values of 650mV open circuit voltage and 40.1 A/mm^2 short circuit current density and 79.7 % on the fill factor, and 20.71% efficiency.

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Keywords: n-PERT; selective-BSF; solar cell

1. Introduction

The PERT (Passivated Emitter, Rear Totally diffused) structure has a high conversion efficiency, especially on the n-type wafer [1]. Its cost has an attractive competition to the p-PERC (Passivated Emitter, Rear Cell). The most

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characteristic point is on its both side light absorption, the bifaciality. This unique structure can boost not only on the cell efficiency but also the module's output power.

The n-type silicon wafers have an enormous potential for wide scale applications in the PV industry due to: (a) Longer minority carrier diffusion lengths [2]. (b) Higher tolerance to the impurities, especially the Fe [3]. (c) No Light-Induced Degradation (LID) [4]. So the n-type silicon wafer will have a more potential competition in future's high efficiency market [5]. The rear side in this article was divided into two different implant dosages region. This forms the PERT cell with selective Back Surface Field(s-BSF). MOTECH Inc. has developed the n-type bifacial cell technology and start to mass produce at the second quarter of 2015. We got the average efficiency 20.65% at 6" inch large wafer area with double side screen printing. We use the industrial manufacturing facility and technology; the Cz n-type silicon wafers, random pyramid texture, SiN_X ARC, SiO_2 and AlO_X passivation. The only difference is: we apply the ion implantation and the masks to form a dot pattern on the phosphorous rear side, using different implant dosages to form an n-PERT cell with s-BSF.

2. Cell process and results

2.1. Experimental

The structure and processing sequence are shown in Figure 1. The cells in this article use the Cz n-type mono-crystalline silicon wafers with the 238.95mm^2 area as substrates. After texturing, we process the boron diffusion and remove the front borosilicate glass (BSG) by HF, and using KOH to polish the rear side. The ion implantation with $POCl_5$ source is used to form the full area BSF (the n^+ region), and implant with the dot pattern mask to form a selective BSF (the n^{++} region). After the activated step of the BSF, we use the atomic layer deposition (ALD) AlO_X as a front (boron) side passivation, then prepare a SiN_X layer on the both sides by the plasma-enhanced chemical vapor deposition (PECVD).

At the rear side, the heavy implant dosage regions are direct contact to the metal, so we use the firing through silver paste with high solid content to form a 400um diameter and under 10um height's metal pad. The second part of the rear side metallization is how to connect all the metal pads and to conduct out the current. We use the floating (non-firing through) silver paste with to cover the fully rear side and connect all the metal contacts formed at the previous step. After the rear side metallization, we use the silver/aluminum paste to form the contact with the front side boron emitter, and send it into the fast-firing furnace to undergo the co-firing process.

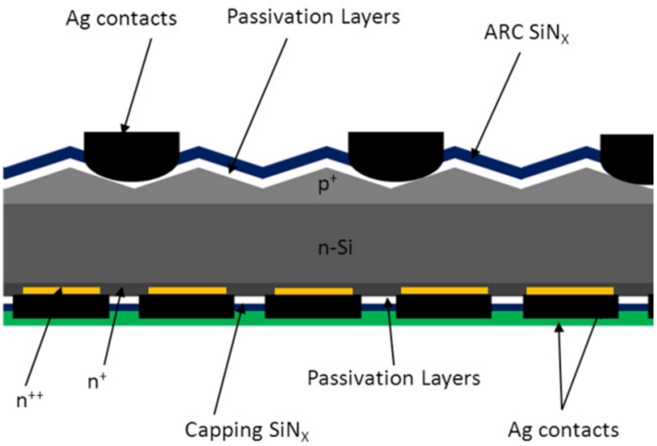

Fig. 1. The nPERT cells with S-BSF structure with metal screen printing on the front (H-pattern) and the rear side (full cover)

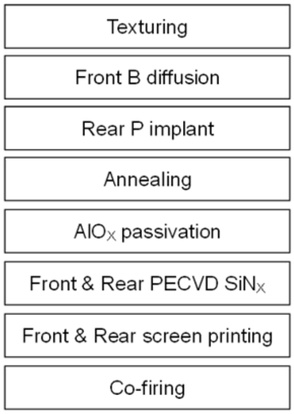

Fig. 2. The processing sequence

2.2. Cell results

Table 1 is the I-V curve and the efficiency of the final cells measured by the BERGER's cell tester. We can find the maximum open-circuit voltage, V_{OC} obtained is 650 mV. The short circuit current density, J_{SC} is 40.1mA/cm^2. The average fill factor is 79.7%, and with this cell structure, we can achieve 20.7% average cell efficiency.

Table 1. I-V characteristics of the champion batch

Cell No.	V_{OC}[mV]	I_{SC}[A]	J_{SC}[mA/cm^2]	R_S[mOhm]	FF[%]	η[%]
1	649	9.56	40.03	2.06	79.57	20.66
2	650	9.54	39.94	1.96	79.50	20.62
3	648	9.57	40.07	2.15	79.73	20.70
4	650	**9.58**	**40.08**	2.21	79.61	20.73
5	**651**	9.57	40.06	2.01	79.91	**20.83**
Average	649	9.57	40.03	2.08	79.66	20.71

2.3. Process improvement

Due to the fully rear side metallization with silver paste will have a big coat, so, we improve this drawback with a lower solid content silver paste, is about 65% of the original paste. We also measure the finish cell efficiency. Table 2 shows the I-V data of the sample using the lower solid content silver paste; it seems comparable to the original sample. Because the fully rear side metal's main function is to connect all the metal pads and it's easy to form an ohmic contact between the metals, so we choose the floating (non-firing through) silver paste not only to connect the metal pads, but to protect the rear side passivation to gain the higher open circuit voltage, V_{OC}. We can say that the full area metallization's thickness can be controlled and keep the series resistance, R_S into a range to get the balance between the performance and the cost. Figure 3 is the SEM cross section imagines of the two different solid content silver pastes. We can found that the low solid content silver paste made the thinner thickness (8um) of the fully rear side metal compare to the thicker (15um) with the high solid content one. We can combine with the cell I-V data in Table 2 and judge that we can change the silver paste to the lower solid content and still with nearly the same electrical properties.

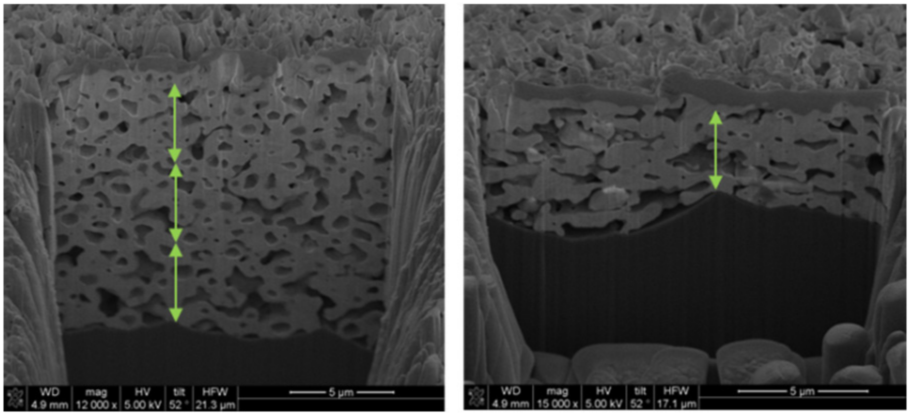

Fig. 3. The FIB Cross-sections of the sample with two different solid contents paste

Table 2. The Relative I-V characteristics of the sample with two different solid contents paste

Paste	V_{OC}[mV]	I_{SC}[A]	J_{SC}[mA/cm2]	R_S[mOhm]	FF[%]	η[%]
Paste H	0	0	0	0	0	0%
Paste L	0.43	0.01	0.04	**+0.2**	**-0.18**	**-0.01%**

*Paste H with 88% solid content and Paste L with 62% solid content.

The way to decrease the Cost of Ownership (CoO) in addition to the reduction of the rear side metallization process cost we can raise the cell or module performance. The most characteristic, charming and impressive of the nPERT cell technology is that it can work on its both cell sides, in other words, they have two efficiency results on the front and rear sides [6], that is so called bifacial cells. The nPERT bifacial cells are employed in double side transparent modules, taking the advantage of the natural albedo from the place where they are mounted in order to increase their power output. Based on this idea, why not to keep the bifacial concept on this s-BSF structure? We modified the original fully rear metallization design to a finger-like pattern. Figure 4 is the schematic diagram, we use the line shape to substitute the fully area metallization for the connection of the metal pads on the heavy doping regions and finally assemble into the busbars. We called it "pseudo-bifi" structure. Table 3 is the electrical properties; front and rear side. This design not only presents the bifacial character but reducing the usage of the silver paste on the rear side. This also can reduce the bowing to a lower extent. Besides above advantages, the greatest benefit on this pseudo-bifi structure is the significant additional power (efficiency) generation from the rear side. The effective efficiency applied for the model calculations are given in the Table. 3. We compared the two different cell rear metal designs; the monofacial and the pseudo- bifi structures. Although the pseudo-bifi design has 0.1% lower than monofacial on the efficiency, due to its lower short circuit current (J_{SC}) and little higher series resistance (R_S). But the bifacialality on the pseuso-bifi structure is noticeable; Table 3 shows the effective efficiency under different assumed albedo. The average rear side efficiency is 10.95%, so there will have a bifacial gain. We can found that when the cell is just at an only 10% albedo's condition the effective efficiency can achieve 21.71%, which is 1% higher than the monofacial structure. If the albedo is much higher, we can get more efficiency gain from the rear side. This bifacial character will make it more competitive, not only reduces the usage of the paste, but also boosts up the performance both on the cells and modules.

Table 3. The Relative I-V characteristics of the sample with two different rear metallization pattern design

Cell Type	Front Side Efficiency[%]	Rear Side Efficiency[%]	Albedo Assumed[%]	Effective Efficiency[%]
Monofacial (fully rear)	20.71	0	0	20.71
Pseudo-bifi (finger-like rear)	20.61	10.95	0	20.61
			10	21.71
			20	22.80
			30	23.90

*Effective efficiency = Front side efficiency + Rear side efficiency.

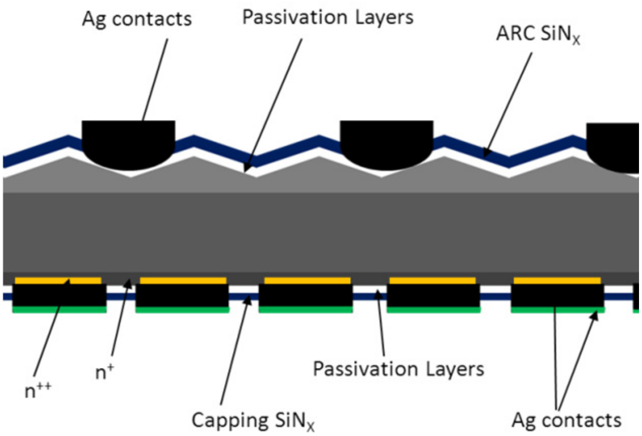

Fig. 4. The nPERT cells with S-BSF structure with metal screen printing on the front (H-pattern) and the rear side (H-pattern).

3. Conclusion

In this article, industrial nPERT solar cell design with the s-BSF structure by the ion implantation was introduced. We try to utilize the implant process's advantage; flexible pattern designation and precisely dosage and position control. The champion cell efficiency can achieve 20.83% and with 20.71% on the average. In the second part, based on the reduction of the cost and the improvement of the efficiency, we changed the rear metal pattern from the full rear to Ag finger like grid in combination with busbar layout, and call it the "pseudo-bifi" structure. Accordingly, the Ag paste consumption of the pseudo-bifi cells is 30% drastically reduced which compares to original full-area Ag layer. In contrast to monofacial design, the pseudo-bifi cells exhibit lighter wafer bow due to the symmetric device structure. The slightly increased series resistance of the pseudo-bifi cells decreases the efficiency by approximately 0.1%abs. The pseudo-bifi cells can achieve the average front side efficiency up to 20.61% and rear side efficiency up to 10.95% measured with an in-house black chuck cell tester. Under the assumed albedo condition the cell efficiency can even over 22% by the rear side contribution. We will continue focusing on the process modification, believing that the potential of the n-type silicon cells and the application of the bifacial cells will rise up in the next coming years.

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